**US Army Corps
of Engineers**
Construction Engineering
Research Laboratories

Performance Analysis of Natural Gas Cooling Technology at Air Force Bases

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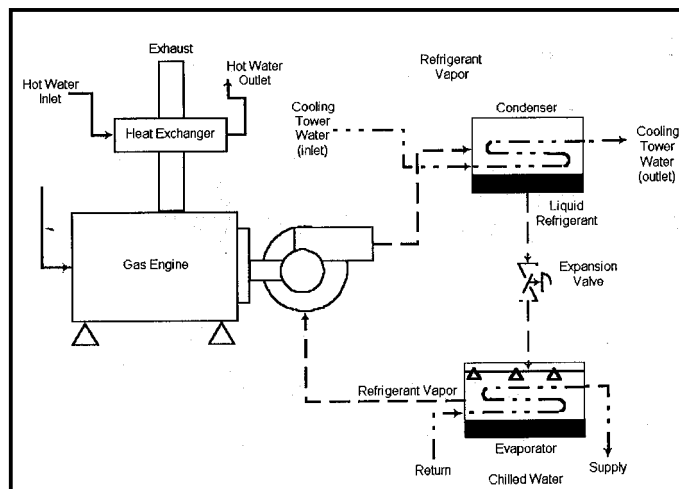
High-efficiency gas-fired cooling equipment is readily available for commercial, institutional, and industrial facilities. Natural gas engine-driven chillers have higher coefficients of performance than any natural gas cooling system and can serve as energy efficient alternatives for new electric chillers. This study monitored the performance of natural gas cooling technologies operating at three Air Force bases during the fiscal year 1998 cooling season and compared the actual performance data to theoretical values. Energy and demand cost analyses were performed to compare each natural gas cooling technology with the energy and demand costs of old and new electric chillers. The study determined that, at the monitored bases, the costs for the natural gas used by the engine-driven chillers were lower than electrical costs used by old and new electric chillers, resulting in an energy cost savings.

Foreword

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1 Introduction

Background

Under the Department of Defense (DOD) Natural Gas Cooling Demonstration Program, three Air Force bases have natural gas engine-driven chiller systems currently in operation: Davis-Monthan Air Force Base (AFB), AZ, Utah Air National Guard (ANG), UT, and Youngstown-Warren Air Reserve Station (ARS), OH. Natural gas-fired cooling technology was chosen for these locations for the same reasons that natural gas cooling has become viable in the commercial market:

- the availability of a new generation of more efficient and reliable gas cooling products
- low natural gas prices
- the desire to cut energy costs and eliminate electric peak demand charges
- the desire to bring operating costs down
- the responsiveness to environmental calls to switch to cleaner, chlorofluoro-carbon (CFC) free technologies
- the need to improve indoor air quality, economically
- the responsiveness to political calls to use an abundant fuel such as natural gas, 95 percent of which is produced domestically.

Currently, high-efficiency gas-fired cooling equipment is readily available for commercial facilities including hotels, office buildings, warehouses, super-markets, and retail outlets; institutions including hospitals, nursing homes, and schools; and industrial facilities (American Gas Cooling Center 1996, p 1).

The three types of natural gas cooling equipment presently on the market are: (1) natural gas engine-driven chillers, (2) absorption cooling systems, and (3) desiccant cooling systems. Of the three types, gas engine-driven chillers have the highest coefficients of performance (COPs), and, in many parts of the United States, have demonstrated the lowest total operating costs (American Gas Cooling Center 1996, p 3).

Engine driven chillers offer important advantages over electric hermetic and electric open drive chillers. The engine driven chiller (Figure 1) is comprised of a reciprocating engine coupled through a gearbox to an open drive chiller.
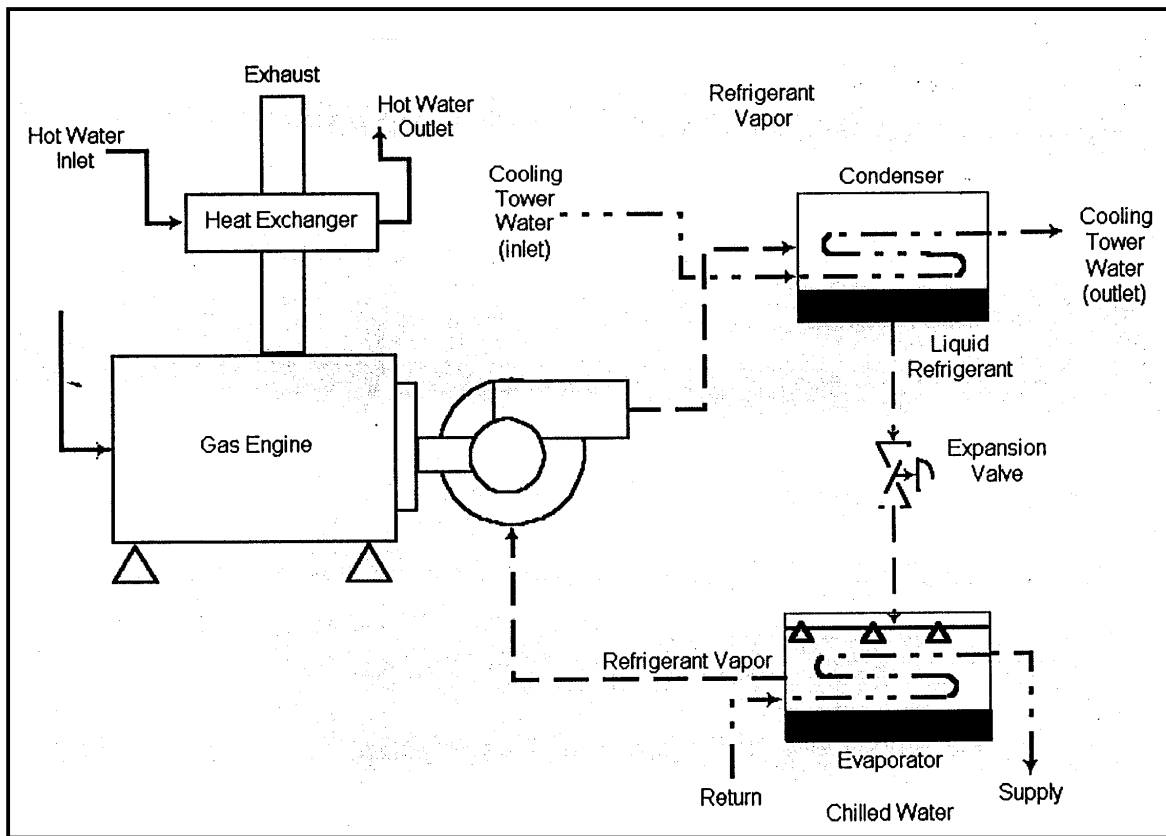
Figure 1. Gas engine-driven chiller.

The electric motor of a hermetic chiller is totally enclosed within a compressor housing, and is cooled by the refrigerant. The additional heat load from the motor, when transferred to the refrigerant, adds 3 to 6 percent in energy consumption. In contrast with an engine-driven chiller, most of the heat that is generated by the engine to drive the compressor can be recovered from the engine's jacket cooling and exhaust systems. This recoverable engine heat does not have to be discharged to the environment through the chiller's condenser (American Gas Cooling Center 1996, p 3).

Natural gas engine-driven chillers use three major types of compressors:

1. *Centrifugal* compressors are available for applications over 400 tons and have been built for systems up to 6,000 tons.

2. *Screw* compressors are used for applications from 100 to 4,000 tons.

3. *Reciprocating* compressors are typically applied to engine-driven systems requiring less than 200 tons (American Gas Cooling Center 1996, p 4).

Typical coefficients of performance (COPs) of natural gas engine-driven chillers at full load range from 1.2 to 2.0 with no heat recovery, 1.5 to 2.25 with jacket water heat recovery, and from 1.7 to 2.4 with both jacket water and exhaust heat recovery. Heat recovery from the jacket coolant and exhaust gas will boost overall energy use (American Gas Cooling Center 1996, p 7).

On the other hand, since the majority of facilities in the United States have electric-driven chillers, personnel are already familiar with the maintenance procedures for electric-drive units. The introduction of gas cooling technology into these facilities will require retraining of personnel or the purchase of maintenance agreements. The costs of these agreements are usually a function of the chiller capacity. (Such agreements are not exclusive to gas engine-driven chillers and can also be purchased for electric-driven chillers.)

The maintenance cost of gas engine-driven chillers is somewhat more expensive than that of electric-driven or absorption chillers, or desiccant dehumidifying systems. Annual maintenance costs are based on the annual equivalent full load hours of operation, maintenance costs, and chiller capacity. The maintenance costs of gas engine-driven chillers are approximately 1.5 to 3 times higher than their electric counterparts; the cost of absorption units and desiccant dehumidifying systems falls somewhere in between.[*]

The U.S. Army Construction Engineering Research Laboratories (CERL) was tasked with monitoring the performance of the natural gas technologies at each base during the FY98 cooling season, and with comparing the actual performance data to theoretical values. As part of this monitoring effort, energy and demand cost analyses were performed to compare each natural gas cooling technology with the energy and demand costs of old and new electric chillers.

Objectives

The overall objective of this study was to monitor and report on the performance of natural gas cooling technologies at Air Force bases. Specific objectives of this part of the monitoring effort were to perform energy and demand cost analyses

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[*] Timothy Pedersen and William Brown, *Advanced Gas Cooling Technology Demonstration Program at Air Force Installations, Fiscal Year 1996*, TR 97/106/ADA327941 (CERL, July 1997), pp 15-16.

to compare natural gas cooling technology at each Air Force Base with the energy and demand costs of old and new electric chillers.

Approach

CERL representatives were available to supervise and evaluate the acceptance testing results for the installed systems. Monitoring equipment was specified for each facility to record data for either 1 or 2 years. Technical and economic aspects of system performance were monitored remotely. Collected data was analyzed to evaluate the effectiveness of gas equipment at each of the demonstration sites.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	2.54 cm
1 ft	=	0.305 m
1 yd	=	0.9144 m
1 sq in.	=	6.452 cm^2
1 sq ft	=	0.093 m^2
1 sq yd	=	0.836 m^2
1 cu in.	=	16.39 cm^3
1 cu ft	=	0.028 m^3
1 cu yd	=	0.764 m^3
1 gal	=	3.78 L
1 lb	=	0.453 kg
°F	=	(°C x 1.8) + 32
1 ton (refrigeration)	=	3.516 kW

2 Natural Gas Cooling Performance Analysis

Data Points Required To Monitor for Performance Analysis

Data points used in monitoring the operation of chillers are best sampled every 15 minutes. The following data points are required to obtain a proper performance analysis for natural gas cooling equipment:

- chilled water supply (CHWS) temperature
- chilled water return (CHWR) temperature
- chilled water (CHW) flow in gallons per minute (gpm)
- natural gas flow rate in standard cubic feet per hour (SCFH).

The CHWS temperature, CHWR temperature, and CHW flow are used to calculate the chiller capacity in tons. Once the tons are calculated, the coefficient of performance (COP) of the chiller can be calculated, given the flow rate and higher heating value (HHV) of natural gas.

Performance Analysis Calculations

Chiller Capacity

The capacity of a chiller, in tons, is determined by the following equation:

$$\text{Tons} = \frac{(\text{CHW Flow}) \ * \ (\text{CHWR Temp} \ - \ \text{CHWS Temp})}{24} \qquad \textbf{Eq. 1}$$

where CHWR Temp and CHWS Temp are expressed in degrees Fahrenheit (°F), and CHW Flow in gpm.

Coefficient of Performance

The coefficient of performance (COP) of the chiller is the standard calculation for rating the performance of cooling equipment. COPs for engine driven chillers can be determined using the following equation:

$$COP = \frac{Tons \ * \ 12,000 \ BTU \ / \ ton \ - \ hr}{Natural \ Gas \ Flow \ (in \ SCFH) \ * \ HHV} \qquad \textbf{Eq. 2}$$

where HHV is generally equal to 1000 BTU/SCF, unless otherwise specified.

Energy and Demand Cost Analysis Calculations

Data was collected from each facility to indicate the peak tonnage produced by the engine-driven chillers each month and the number of hours at various average loads during the entire monitoring period. Peak monthly tonnage information is necessary to estimate the demand charges that would result if electric motor-driven chillers are used instead of natural gas engine-driven chillers. Load duration information is required to estimate energy costs. The monthly electrical demand cost would be computed as follows.

If no ratchet is applied:

$$Demand \ Cost \ = \ \left(\frac{Tons_{actual}}{\left(Tons_{actual} \right)_{max}} \right)^2 * \left(\frac{kW}{ton} \right)_{new} * \left(Tons_{actual} \right)_{max} * \ Demand \ Charge \ \textbf{Eq. 3}$$

where:

$Tons_{actual}$ = Monthly peak load

$(kW/ton)_{new}$ = Efficiency of new electric chiller at full load

$(Tons_{actual})_{max}$ = Maximum monthly peak load over selected monitoring period.

If a ratchet is applied, and the load ratio $(Tons_{actual}/[Tons_{actual}]_{max})$ is greater than the ratchet percentage:

$$Demand \ Cost \ = \ \frac{Tons_{actual}}{\left(Tons_{actual} \right)_{max}} * \left(\frac{kW}{ton} \right)_{new} * \ Tons_{design} * Demand \ Charge \qquad \textbf{Eq. 4}$$

where $\text{Tons}_{\text{design}}$ = Full-load capacity of chiller.

If a ratchet is applied, and the load ratio ($\text{Tons}_{\text{actual}}/[\text{Tons}_{\text{actual}}]_{\text{max}}$) is less than the ratchet percentage:

$$\text{Demand Cost} = \left(\frac{\% \text{ Ratchet}}{100} \right) * \left(\frac{kW}{ton} \right)_{\text{new}} * \text{Tons}_{\text{design}} * \text{Demand Charge} \qquad \textbf{Eq. 5}$$

Load duration information includes the number of hours a chiller operates within specified ton ranges. Depending on how the ton ranges are grouped, the ton-hours would be computed as follows:

$$\text{Ton} - \text{Hours} = \sum_{i=1}^{n} (\text{Avg Ton Range} * \text{Hours in Ton Range}) \qquad \textbf{Eq. 6}$$

The energy cost would then be computed by the following equation:

$$\text{Energy Cost} = \left(\frac{kW}{ton} \right)_{\text{new}} * \text{Ton - Hours} * \text{Energy Charge} \qquad \textbf{Eq. 7}$$

3 Results of Performance Analysis

Overview of Air Force Facilities Monitored

Davis-Monthan Air Force Base, AZ

Davis-Monthan AFB currently has two 650-ton R-123 York-Caterpillar gas engine-driven chillers in operation. The chillers are located at the central plant, Building 5101, providing service to 10 dormitories and the following five buildings:

1. Building 2300 (Combat Support Center)
2. Building 2441 (Base Exchange Complex)
3. Building 3200
4. Building 3203 (Bowling Alley)
5. Building 4100 (Dining Hall).

Chiller #1 is located in the western part of the central plant, while Chiller #2 is located in the eastern part of the central plant. Startup for the two chillers began in July 1997, and commissioning was completed in September 1997. Data points monitored during its operation are collected using the following Synergistics Model C-180E survey meter recorders: 03629 for Chiller #2, and 03630 for Chiller #1. Each chiller has the following design parameters: 2.16 full-load COP, 45 °F chilled water supply temperature, 57 °F chilled water return temperature, and 1300 gpm of chilled water flow. The Davis-Monthan AFB point of contact is Steve Weleck, tel.: (520) 228-4253.

Utah Air National Guard, UT

Utah ANG currently has two, 55-ton R-22 Alturdyne gas engine-driven air-cooled chillers in operation. One chiller provides service to Building 40 (Squadron Operations Building), while the other chiller provides service to Building 50 (Squadron Administrative Building). Startup for the two chillers began in May 1997, and commissioning was completed in August 1997. Heat recovery options are installed on each chiller to operate as a source for domestic hot water. Data points monitored during its operation are collected daily for historical reporting and analysis using a Direct Digital Control (DDC) interface controlled by an

operator workstation. The chiller has the following design parameters: 0.98 full-load COP, 1.04 COP at 75 percent load, 0.95 COP at 50 percent load, 0.80 COP at 25 percent load, 45 °F chilled water supply temperature, 55 °F chilled water return temperature, and 132 gpm of chilled water flow. The Utah ANG POC is Steve Hill, tel.: (801) 595-2291.

Youngstown-Warren Air Reserve Station, OH

Youngstown-Warren ARS currently has one, 140-ton NAPPS gas engine-driven water-cooled chiller package in operation carrying a refrigerant mixture composed of water and 40 percent ethylene glycol concentration. The chiller provides service to Building 407 (Composite Reserve Forces Operational Training Facility). Data points monitored during its operation are collected using the Johnson Controls METASYS™ Companion system. The chiller has the following design parameters: 1.34 full-load COP, 1.62 COP at 93.64 tons, 1.65 COP at 88.85 tons, 1.79 COP at 84.78 tons, 1.73 COP at 79.44 tons, 44 °F chilled water supply temperature, 54 °F chilled water return temperature, and 330 gpm of chilled water flow. The Youngstown-Warren ARS POC is George Mocker, tel.: (330) 609-1063.

Comparison of Design and Actual Values

Results from Davis-Monthan AFB

Data for the two, 650-ton, gas engine-driven chillers was acquired for the months of December 1997 through July 1998. During this period, Chiller #1 used 3,281 MBtu of natural gas, and Chiller #2 used 2,645 MBtu of natural gas. The unit cost of natural gas is $3.33/MBtu. Based on the foregoing, the cost for the natural gas by Chiller #1 would be $3.33/MBtu x 3,281 MBtu = $10,926, and the cost for the natural gas by Chiller #2 would be $3.33/MBtu x 2,645 MBtu = $8,808. Information from the base indicates there is a charge of $10.28/kW for demand (with a 66.7 percent ratchet applied), a summer energy charge of $0.047457/kWh from May to October, and a winter energy charge of $0.045084/kWh from November to April. Tables 1 and 2, respectively, show the demand charges for Chillers #1 and #2 with a full load efficiency of 0.55 kW/ton for a new electric chiller. Figures 2 and 3 show the peak tonnages produced by the engine-driven chillers each month.

From Table 1, the total demand charges for the period = $24,178.

From Table 2, the total demand charges for the period = $18,164.

Tables 3 and 4 show the results of the ton-hour calculations for the entire monitoring period for each chiller.

Table 1. Davis-Monthan AFB Chiller #1 results: demand charges.

Month	Peak Load	COP	When Peak Occurred		Demand Cost
			Date	Time	
Dec 97	579.05	2.40	12/29/97	16:07	$3,491
Jan 98	423.02	2.23	1/28/98	11:52	$2,550
Feb 98	432.46	2.32	2/27/98	9:44	$2,607
Mar 98	392.85	2.14	3/13/98	5:14	$2,451
Apr 98	502.47	1.47	4/23/98	17:00	$3,029
May 98	609.66	1.78	5/19/98	16:00	$3,675
Jun 98	538.75	2.21	6/18/98	5:45	$3,248
Jul-98	518.78	2.07	7/19/98	23:45	$3,127

Table 2. Davis-Monthan AFB chiller #2 results: demand charges.

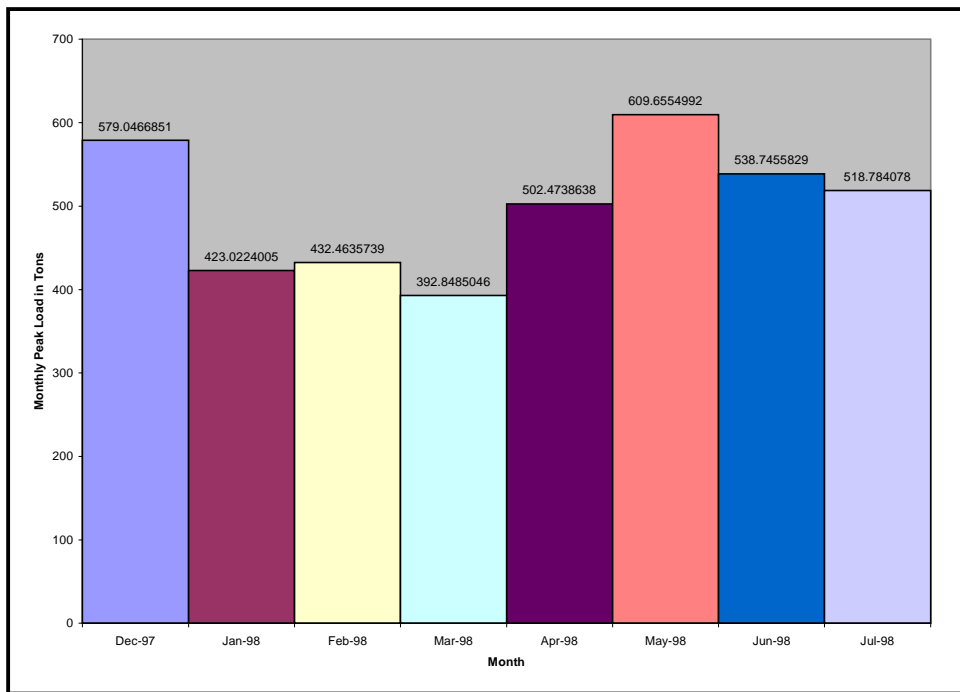| Month	Peak Load	COP	When Peak Occurred		Demand Cost
			Date	Time	
Dec 97	310.26	1.76	12/30/97	13:21	$2,451
Jan 98	626.33	1.92	1/27/98	13:27	$3,675
Feb 98	525.5	1.71	2/26/98	10:29	$3,083
Mar 98	542.55	1.78	3/27/98	3:13	$3,184
Apr 98	N/A	N/A	N/A	N/A	N/A
May 98	N/A	N/A	N/A	N/A	N/A
Jun 98	508.05	1.49	6/30/98	13:15	$2,981
Jul-98	475.51	1.39	7/14/98	14:30	$2,790

Figure 2. Davis-Monthan AFB chiller #1 peak loads.
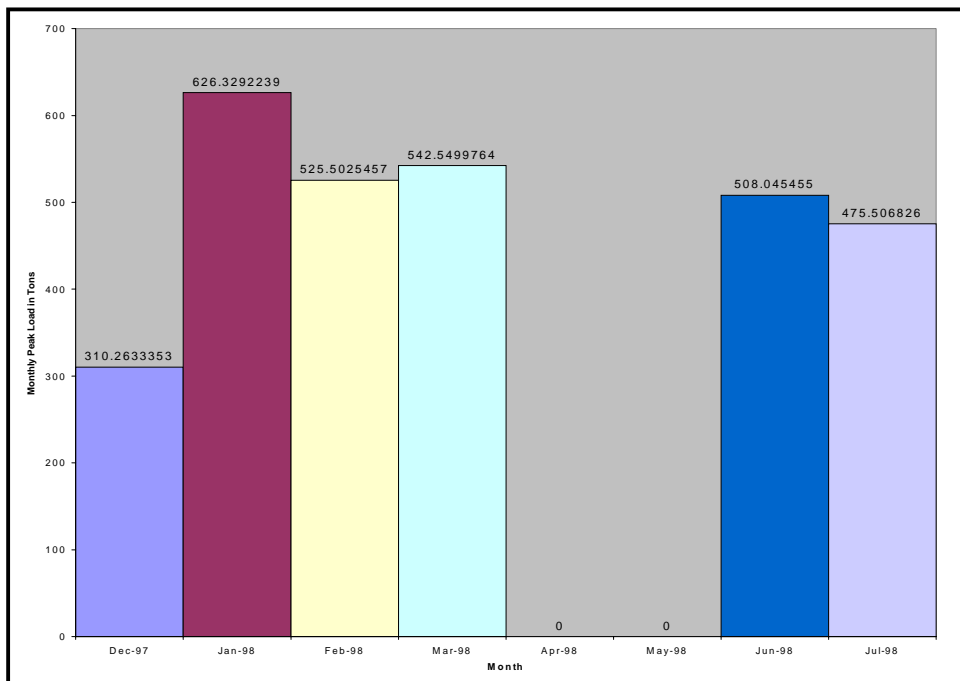
Figure 3. Davis-Monthan AFB chiller #2 peak loads.

Table 3. Davis-Monthan AFB chiller #1 ton-hours by ton range.

	Dec 97 – Apr 98		May – Jul 98	
Ton Range	**Hours**	**Ton-Hours**	**Hours**	**Ton-Hours**
16.25	237.75	3863.44	38.75	629.69
48.75	8.75	426.56	0.50	24.38
81.25	14.75	1198.44	1.25	101.56
113.75	36.00	4095	3.25	369.69
146.25	70.25	10274.06	29.75	4350.94
178.75	58.00	10367.5	198.00	35392.5
211.25	28.00	5915	270.00	57037.5
243.75	7.25	1767.19	235.50	57403.13
276.25	5.25	1450.31	113.75	31423.44
308.75	5.00	1543.75	42.25	13044.69
341.25	4.00	1365	28.50	9725.63
373.75	5.00	1868.75	38.50	14389.38
406.25	5.00	2031.25	45.75	18585.94
438.75	1.75	767.81	96.50	42339.38
471.25	1.25	589.06	17.75	8364.69
503.75	0.75	377.81	2.25	1133.44
536.25	0.00	0.0	1.75	938.44
568.75	0.50	284.38	1.50	853.13
601.25	0.00	0.00	1.00	601.25
633.75	0.00	0.00	0.00	0.00
Totals		**48185.31**		**296708.80**

Using the full load efficiency of 0.55 kW/ton and the appropriate energy charges, the energy costs are:

For Chiller #1:

Energy cost = 0.55 kW/ton x [(48,185.31 ton-hrs x $0.045084/kWh) + (296,708.8 ton-hrs x $0.047457/kWh)] = $8,939

For Chiller #2:

Energy cost = 0.55 kW/ton x [(50,671.59 ton-hrs x $0.045084/kWh) + (194,033.14 ton-hrs x $0.047457/kWh)] = $6,321

Table 4. Davis-Monthan AFB chiller #2 ton-hours by ton range.

Ton Range	Dec 97 – Apr 98		May – Jul 98	
	Hours	Ton-Hours	Hours	Ton-Hours
16.25	192.50	3128.13	90.25	1466.56
48.75	10.25	499.69	0.25	12.19
81.25	105.00	8531.25	0.25	20.31
113.75	5.25	597.19	0.25	28.44
146.25	12.75	1864.69	0.00	0.00
178.75	55.00	9831.25	1.50	268.13
211.25	28.00	5915	56.75	11988.44
243.75	19.50	4753.13	152.00	37050.00
276.25	16.00	4420	154.25	42611.56
308.75	6.50	2006.88	137.00	42298.75
341.25	2.75	938.44	101.50	34636.88
373.75	2.00	747.50	28.75	10745.31
406.25	2.00	812.50	13.50	5484.38
438.75	2.00	877.50	15.00	6581.25
471.25	3.50	1649.38	1.25	589.06
503.75	3.75	1889.06	0.50	251.88
536.25	2.75	1474.69	0.00	0.00
568.75	0.75	426.56	0.00	0.00
601.25	0.25	150.31	0.00	0.00
633.75	0.25	158.44	0.00	0.00
Totals		**50671.59**		**194033.14**

The total electrical cost for each new electric chiller for the period would be:

Chiller #1:

$24,178 + 8,939 = $33,117

Chiller #2:

$18,164 + 6,321 = $24,485

The efficiency of the old electric chiller at the central plant was 0.85 kW/ton. Regardless of load, the demand costs would then be:

For Chiller #1:

      Dec 97:   579.05 tons x 0.85 kW/ton x $10.28/kW = $5,060
      Jan 98:   423.02 tons x 0.85 kW/ton x $10.28/kW = $3,697
      Feb 98:   432.45 tons x 0.85 kW/ton x $10.28/kW = $3,779
      Mar 98:   392.85 tons x 0.85 kW/ton x $10.28/kW = $3,443
      Apr 98:   502.47 tons x 0.85 kW/ton x $10.28/kW = $4,391
      May 98:   609.66 tons x 0.85 kW/ton x $10.28/kW = $5,327
      Jun 98:   538.75 tons x 0.85 kW/ton x $10.28/kW = $4,708
      Jul 98:   518.78 tons x 0.85 kW/ton x $10.28/kW = $4,533

For Chiller #2:

      Dec 97   310.26 tons x 0.85 kW/ton x $10.28/kW = $2,711
      Jan 98   626.33 tons x 0.85 kW/ton x $10.28/kW = $5,473
      Feb 98   525.5 tons   x 0.85 kW/ton x $10.28/kW = $4,592
      Mar 98   542.55 tons x 0.85 kW/ton x $10.28/kW = $4,741
      Apr 98   No data available
      May 98   No data available
      Jun 98   508.05 tons x 0.85 kW/ton x $10.28/kW = $4,439
      Jul 98   475.51 tons x 0.85 kW/ton x $10.28/kW = $4,155

The total demand costs for each chiller during the monitoring period would be:

      Chiller #1: $34,938
      Chiller #2: $26,111

The electrical energy cost would then be:

For Chiller #1:

      Energy cost = 0.85 kW/ton x [(48,185.31 ton-hrs x $0.045084/kWh) + (296,708.8 ton-hrs x $0.047457/kWh)] = $13,815

For Chiller #2:

      Energy cost = 0.85 kW/ton x [(50,671.59 ton-hrs x $0.045084/kWh) + (194,033.14 ton-hrs x $0.047457/kWh)] = $9,769

If the old electric chillers were used, the total electrical cost would then be:

      Chiller #1: $34,938+ 13,815 = $48,753
   Chiller #2: $26,111 + 9,769 = $35,880

Table 5 summarizes the cost comparison for Davis-Monthan AFB.

Table 5. Cost comparison of old vs. new chillers, Davis-Monthan AFB.

Chiller Type	Chiller #1	Chiller #2
Old electric chiller	$48,753	$35,880
New electric chiller	$33,117	$24,485
New gas chiller	$10,926	$8,808

Results from Utah ANG

Data for the two, 55-ton, gas engine-driven chillers was acquired for the months of May through July 1998. Based on design COPs at 25, 50, 75, and 100 percent, the natural gas flow estimates for different chiller capacities can be determined by interpolation. During this period, the chiller in Building 40 used an estimate of 189 MBtu of natural gas, and the chiller in Building 50 used an estimated of 108 MBtu of natural gas. The unit cost of natural gas is $3.59/MBtu. Based on the foregoing, the estimated cost for the natural gas by the chiller in Building 40 would be $3.59/MBtu x 189 MBtu = $679, and the estimated cost for the natural gas by Chiller #2 would be $3.59/MBtu x 108 MBtu = $388. Information from the base indicates there is a charge of $8.45/kW for demand (with no ratchet applied), and an energy charge of $0.029/kWh. Tables 6 and 7, respectively, show the demand charges for the chillers in Buildings 40 and 50 with a full load efficiency of 0.90 kW/ton for a new electric chiller. Figures 4 and 5 show the peak tonnages produced by the engine-driven chillers each month.
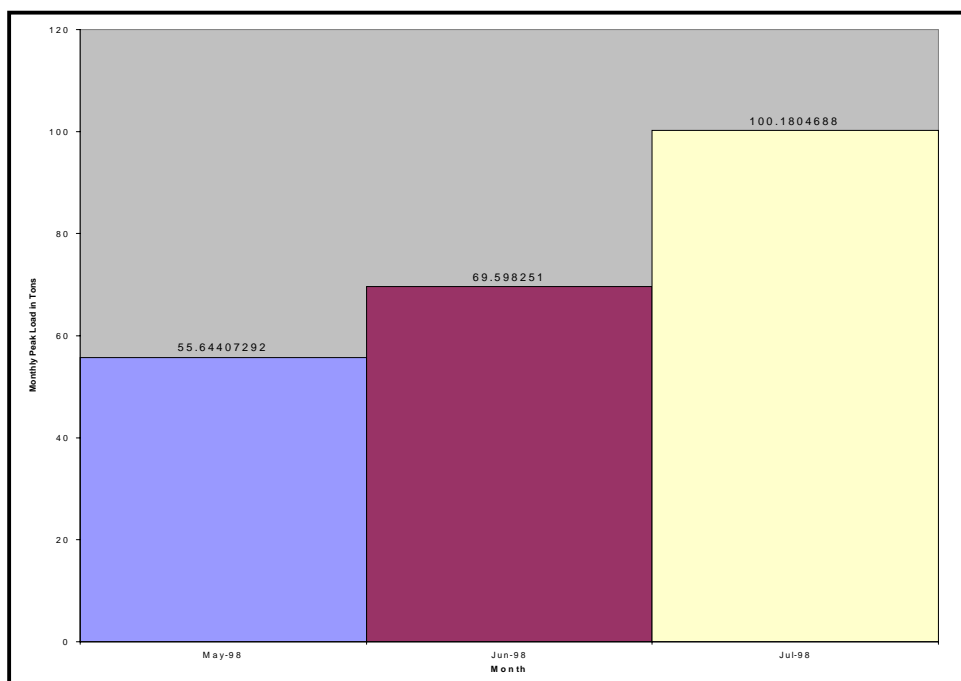
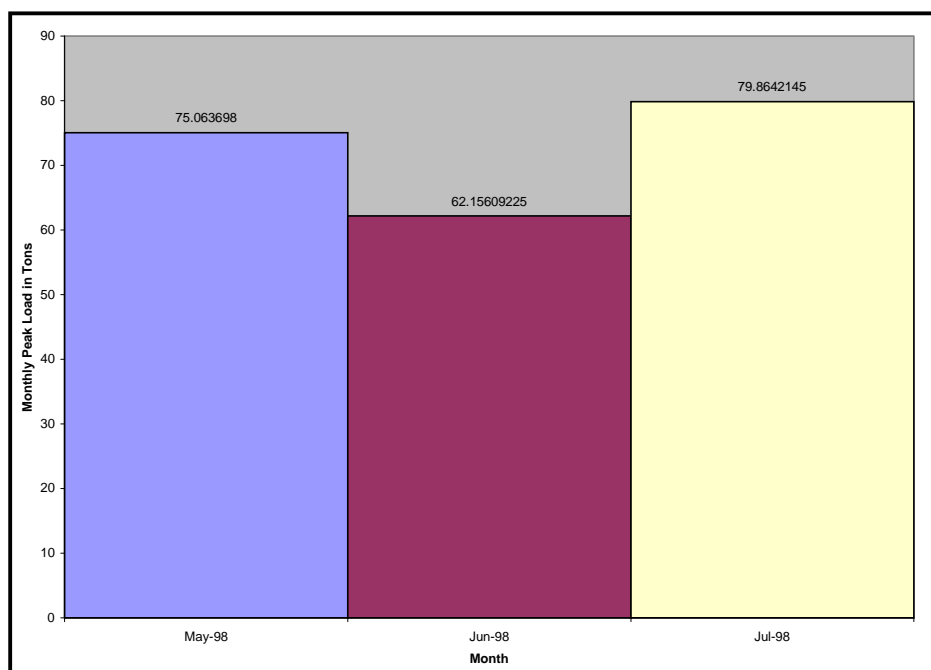**Figure 4. Utah ANG Bldg. 40 chiller peak loads.**

Figure 5. Utah ANG Bldg. 50 chiller peak loads.

From Table 6, the total demand charges for the period = $1,365.

From Table 7, the total demand charges for the period = $1,512.

Tables 8 and 9 show the results of the ton-hour calculations for the entire monitoring period for each chiller.

Table 6. Utah ANG Bldg. 40 chiller results: demand charges.

| Month | Peak Load | COP | When Peak Occurred | | Demand Cost |
			Date	Time	
May 98	55.64	0.98	5/31/98	10:12	$235
Jun 98	69.60	0.95	6/4/98	17:11	$368
Jul-98	100.18	0.91	7/7/98	13:21	$762

Table 7. Utah ANG Bldg. 50 chiller results: demand charges.

| Month | Peak Load | COP | When Peak Occurred | | Demand Cost |
			Date	Time	
May 98	75.06	0.94	5/26/98	12:37	$537
Jun 98	62.16	0.96	6/25/98	5:50	$368
Jul-98	79.86	0.93	7/26/98	13:20	$607

Table 8. Utah ANG Bldg. 40 chiller ton-hours by ton range.

Ton Range	Hours	Ton-Hours
3.4375	10.00	34.38
10.3125	13.00	134.06
17.1875	108.50	1864.84
24.0625	390.75	9402.42
30.9375	81.25	2513.67
37.8125	8.50	321.41
44.6875	1.50	67.03
51.5625	4.00	206.25
Total		**14544.06**

Table 9. Utah ANG Bldg. 50 chiller ton-hours by ton range.

Ton Range	Hours	Ton-Hours
3.4375	473.75	1628.52
10.3125	13.50	139.22
17.1875	3.75	64.45
24.0625	11.25	270.70
30.9375	28.00	866.25
37.8125	63.25	2391.64
44.6875	31.75	1418.83
51.5625	15.75	812.11
Total		**7591.72**

Using the full load efficiency of 0.90 kW/ton and the appropriate energy charge, the energy costs are:

Building 40 Chiller:

Energy cost = 0.90 kW/ton x 14,544.06 ton-hrs x $0.029/kWh = $380

Building 50 Chiller:

Energy cost = 0.90 kW/ton x 7,591.72 ton-hrs x $0.029/kWh = $198

The total electrical cost for each new electric chiller for the period would be:

Building 40 Chiller: $1,365 + 380   = $1,745
Building 50 Chiller: $1,512 + 198   = $1,710

The efficiency of the old electric chiller at the central plant was 1.20 kW/ton. Regardless of load, the demand costs would then be:

For Building 40:

    May 98:   55.64 tons x 1.20 kW/ton x $8.45/kW   = $564
    Jun 98:   69.6 tons   x 1.20 kW/ton x $8.45/kW   = $706
    Jul 98:   100.18 tons x 1.20 kW/ton x $8.45/kW   = $1,016

For Building 50:

    May 98:   75.06 tons x 1.20 kW/ton x $8.45/kW   = $761
    Jun 98:   62.16 tons x 1.20 kW/ton x $8.45/kW   = $630
    Jul 98:   79.86 tons x 1.20 kW/ton x $8.45/kW   = $810

The total demand costs for each chiller during the monitoring period would be:

    Building 40 Chiller: $2,286
    Building 50 Chiller: $2,201

The electrical energy cost would then be:

Building 40 Chiller:

    Energy cost = 1.20 kW/ton x 14,544.06 ton-hrs x $0.029/kWh = $506

Building 50 Chiller:

    Energy cost = 1.20 kW/ton x 7,591.72 ton-hrs x $0.029/kWh = $264

If the old electric chillers were used, the total electrical cost would then be:

    Building 40 Chiller: $2,286 + 506 = $2,792
    Building 50 Chiller: $2,201 + 264 = $2,465

Table 10 summarizes the cost comparison for Utah ANG.

Table 10. Cost comparison of old vs. new chillers, Utah ANG.

Chiller Type	Bldg. 40 Chiller	Bldg. 50 Chiller
Old electric chiller	$2,792	$2,465
New electric chiller	$1,745	$1,710
New gas chiller	$679 (estimate)	$388 (estimate)

Results from Youngstown-Warren ARS

Data for the 140-ton, gas engine-driven chillers was acquired for the months of June through July 1998. Based on part-load COPs at 79.44 tons, 84.78 tons, 88.85 tons, and 93.64 tons, the natural gas flow estimates for different chiller capacities can be determined by interpolation. During this period, the chiller

used an estimate of 218 MBtu of natural gas. The unit cost of natural gas is $4.34/MBtu. Based on the foregoing, the cost for the natural gas by the 140-ton chiller would be $4.34/MBtu x 218 MBtu = $946. Information from the base indicates there is a charge of $18.36/kW for demand (with no ratchet applied), and an energy charge of $0.037/kWh. Table 11 shows the demand charges for the chiller in Building 407 with a full load efficiency of 1.20 kW/ton for a new electric chiller. Figure 6 shows the peak tonnages produced by the engine-driven chillers each month.

From Table 11, the total demand charges for the period = $4,174.

Table 12 shows the results of the ton-hour calculations for the entire monitoring period for the chiller.

Table 11. Youngstown-Warren ARS chiller results: demand charges.

Month	Peak Load	COP	When Peak Occurred		Demand Cost
			Date	Time	
Jun 98	104.82	1.57	6/30/98	10:50	$2,309
Jul 98	94.20	1.62	7/28/98	11:30	$1,865
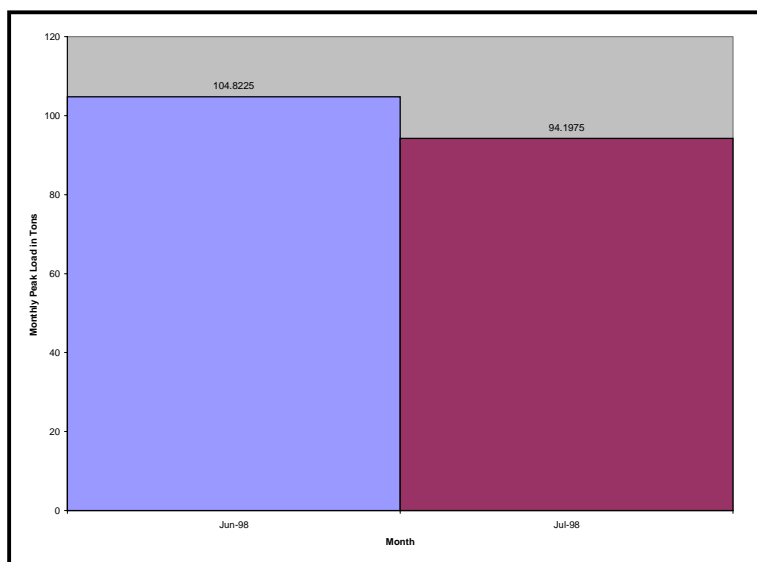
Figure 6. Youngstown-Warren ARS chiller peak loads.

**Table 12. Youngstown-Warren ARS Bldg. 407
chiller ton-hours by ton range.**

Ton Range	Hours	Ton-Hours
4.375	27.75	121.41
13.125	3.25	42.66
21.875	7.75	169.53
30.625	156.50	4792.81
39.375	193.00	7599.38
48.125	90.50	4355.31
56.875	30.00	1706.25
65.625	11.00	721.88
74.375	2.50	185.94
83.125	0.75	62.34
91.875	0.25	22.97
100.625	0.50	50.31
109.375	0.00	0.00
118.125	0.00	0.00
126.875	0.00	0.00
135.625	0.00	0.00
Total		**19830.79**

Using the full load efficiency of 1.20 kW/ton and the appropriate energy charge, the energy cost is:

Energy cost = 1.20 kW/ton x 19,830.79 ton-hrs x $0.037/kWh = $880

The total electrical cost for a new electric chiller for the period would be:

Building 407 Chiller: $4,174 + 880 = $5,054

The efficiency of the old electric chiller at the central plant was 1.35 kW/ton. Regardless of load, the demand costs would then be:

Jun 98: 104.82 tons x 1.35 kW/ton x $18.36/kW = $2,598
Jul 98:   94.2 tons x 1.35 kW/ton x $18.36/kW   = $2,335

The total demand cost for the chiller during the monitoring period would be $4,933.

The electrical energy cost would then be:

Energy cost = 1.35 kW/ton x 19,830.79 ton-hrs x $0.037/kWh = $991

If the old electric chiller were used, the total electrical cost would then be:

Building 407 Chiller: $4,933 + 991 = $5,924

Table 13 summarizes the cost comparison for Youngstown-Warren ARS.

Table 13. Cost comparison of old vs. new chillers, Youngstown-Warren ARS.

Chiller	Cost
Old electric chiller	$5,924
New electric chiller	$5,054
New gas chiller	$ 946 (estimate)

4 Conclusion and Recommendations

Conclusion

This study provided performance monitoring data for natural gas cooling technologies operating at three Air Force demonstration facilities, based on the FY98 cooling season. Both theoretical and actual performance values for each natural gas cooling technology were compared for validation of their operation. The technical and economical aspects of operable natural gas cooling equipment performance were monitored on successful commissioning and functional performance testing acceptability. Energy and demand cost analyses were performed to compare each natural gas cooling technology with the energy and demand costs of old and new electric chillers.

At the three monitored Air Force bases, the costs for the natural gas used by the engine-driven chillers were lower than electrical costs used by old and new electric chillers, resulting in an energy cost savings (Tables 5, 10, and 13; pp 15, 18, and 21, respectively).

Recommendations

It is recommended that data points for CHWS and CHWR temperatures and chilled water flow be documented every 15 minutes. To improve performance and acquire a more accurate savings, it is also recommended that each Air Force facility under the Natural Gas Cooling Technology Program provide minute-by-minute readings of natural gas flow, as opposed to instantaneous values every 15 minutes.

In cases where the remote operator is unavailable to download the trend data on a daily basis due to leave or temporary duty (TDY), it is recommended that the proper communications or datalogger software be used to automatically transfer data to the remote operator's computer workstation. Automatic data transfer should occur in the early morning every 24 hours via modem from the installation's host operator workstation to the remote monitoring site (including weekends and holidays). Without automatic data transfer, the historical trend data provided by the host workstation may not be stored permanently. If the

remote operator does not download the trend data in time, valuable data may be lost. Such missing data could compromise the accuracy of performance and cost results.

CERL plans to provide future reports on natural gas cooling technology performance at Warner-Robins AFB, GA, and Hanscom AFB, MA. Warner-Robins AFB currently has two gas engine-driven chiller units installed, with commissioning to occur during FY99. Hanscom AFB is currently involved in the construction and installation phases of one gas engine-driven chiller unit at their Central Energy Plant, with construction to be completed by the end of 1999. CERL will monitor the performance of each of the chillers at these bases once successful commissioning and acceptance testing has been done.

Finally, it is recommended that USACERL representatives monitor any facilities that will complete successful commissioning and acceptance testing of natural gas cooling equipment for performance to document the actual savings incurred.

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Abbreviations and Acronyms

AFB	Air Force Base
AFCESA	Air Force Civil Engineer Support Agency
ANG	Air National Guard
ARS	Air Reserve Station
Btu	British Thermal Unit
CFC	chlorofluorocarbon
CHW	chilled water
CHWR	chilled water return
CHWS	chilled water supply
COP	Coefficient of Performance
DDC	direct digital control
DOD	Department of Defense
FY	fiscal year
gpm	gallons per minute
HHV	higher heating value
kW	kilowatt
kWh	kilowatt-hour
MBtu	million British Thermal Units
SCF	standard cubic feet
SCFH	standard cubic feet per hour
TDY	temporary duty
CERL	U.S. Army Construction Engineering Research Laboratories

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